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Symposium on

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Synnposium on

REMOTE SENSING IN THE POLAR REGIONS

Highlights of a symposium held at Easton, Maryland on March 6, 7, and 8, 1968 under the auspices of The Arctic Institute of North America with financial support of

The Office of Naval Research, Department of the Navy

The Office of the Chief of Research and Development, Department of the Army

The National Science Foundation

The Geological Survey, Department of the Interior

"...we are incapable of rising through to the upper surface of the air. For if anyone could make his way to the top of it ... he would behold the world above us, and if human nature were fit to endure the vision, he would understand that there is the real firmament, and the true light and the earth as it really is."--Socrates

Remote Sensing in the Polar Regions

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Remote Sensing in the Polar Regions

INTRODUCTION

Purpose of the Symposium

The Arctic Institute of North America long has been interested in encouraging full and specific attention to applications of remote sensing to polar-research problems. With the financial support of the Office of Naval Research, Department of the Navy; the Office of the Chief of Research and Development, Department of the Army; the National Science Foundation; and the Geological Survey, Department of the Interior, the Institute was able to hold a symposium on that subject at Easton, Maryland, on March 6, 7, and 8, 1968. The major purpose of the symposium was to acquaint scientists and technicians concerned with remote sensing with some of the special problems of the polar areas and, in turn, to acquaint polar scientists with the potential of the use of remote sensing. It was felt that those concerned with polar-research problems--in whatever scientific discipline--should take appropriate steps to assure that all possible advantage is taken of the most up-to-date and sophisticated practices and techniques, including the latest developments in remote sensing. It was recognized that the polar regions are especially interesting as places to apply remote-sensing techniques both because of certain

special characteristics of those regions and because of the difficulty and expense of obtaining the information by other means. The Symposium therefore was designed to foster an exchange of ideas between the users and potential users of remote sensing, and instrumentation and interpretation specialists. The special requirements for the polar regions were to be given to the remote-sensing specialists who in turn were to explain what they have to offer now and prospectively in the future.

Organization of the Symposium

The Symposium was of the discussion type and was organized by scientific disciplines, or groups of disciplines, into seven panels (Appendix 1, p. 62). Each session was led by a panel chairman who guided the discussion of four or five panelists, including in each case one or more persons knowledgeable in remote-sensing techniques and problems. All present were encouraged to participate, and they did participate to the extent that they wished within the limits of available time.

About 80 persons attended as participants or as observers (Appendix 2, p. 63). In addition, a few guests also were present. Participants were those who had been invited either as panel chairmen or as panel members. Observers were those professionally interested in the discussions. Many of them also took part in the discussions. The General Chairman of the Symposium was Henri Bader of the Institute of Marine

Sciences of the University of Miami. Dr. Bader also prepared from the tapes that recorded the discussions much of the material on which this report is based.

The Symposium opened on March 6 with an evening dinner session that was designed to give registrants an opportunity to meet each other and to hear two presentations aimed at putting the Symposium into perspective and outlining the procedure planned. A short keynote talk was given by John C. Reed of the Arctic Institute. The main talk was by W. A. Fischer of the Geological Survey who discussed Remote Sensing--Today and Tomorrow. Panel discussions began on March 7. No attempt has been made to report the discussions verbatim. This report includes only major points of discussion, conclusions, and recommendations. The discussions were recorded on tape and are on file in the Arctic Institute. They can be consulted by making application to the Washington Office of the Institute.

General Results

During the Symposium a good deal of progress was made in mutually informing the disciplinary scientists and the remote-sensing specialists of many of the requirements of the environmental scientists and of the present and potential capabilities of remote sensors. It became apparent that the polar regions do hold some special interest from the remote-sensing standpoint. The scarcity of satellites in high-latitude

orbits was noted.

In some respects remote sensing in the polar regions is no different than elsewhere. In other respects the polar regions present special problems because of certain extremes such as low temperatures, low pollution levels, long periods of light and darkness, presence of large amounts of snow and ice, and water saturation of the surface layer. Furthermore, access to and sojourn in the polar regions is much more expensive than elsewhere and as a result, remote sensing, especially by satellite, can be economical. Additionally, the value of remote sensing is enhanced because of the low density of surface observations.

A great deal of determination is necessary to follow through on a remote-sensing requirement. Systems analysis, financing, development, construction, testing, operational application, and electronic data processing may be needed. But the challenge is interesting, exciting, and promising within the mainstream of science, scientific technology, and information processing. The inefficient use of remote sensing is an invitation to expensive failure.

The substantive results of the Symposium will be set forth in a little more detail in the remainder of this report. In general a start has been made in introducing to each other the supplier and the user of remote sensing, especially in the polar regions, and it is hoped

that the introduction will lead to a close and mutually productive association. Already the results of the Symposium have been of specific use in placing the special problems of the polar regions before the Fifth Symposium on Remote Sensing of Environment held by the Institute of Science and Technology of the University of Michigan in Ann Arbor in April 1968.

THE SYMPOSIUM

Background

In 1967 The Arctic Institute of North America designated a Subcommittee of its Research Committee, called the Satellite Subcommittee, to review from time to time the applicability of remote sensing to polar-research problems and to keep the Institute advised as to how it might insure that developing techniques would be applied, when appropriate, to the areas of special concern to the Institute. In the discussion that led to the designation of the Subcommittee were mentioned such specific subjects of interest as the distribution, number, and movement of some large arctic mammals; the distribution and motion of sea ice; the number, origin, and distribution of ice islands in the Arctic Ocean; auroral studies; the distribution of permafrost; the heat budget of the Arctic Ocean; and the breakup patterns of rivers and lakes. The Institute's interest was stimulated also by the developing plans of the U. S. Geological Survey for an Earth Resources Observation Satellite (EROS).

NASA in presenting in May 1967 its Research and Development Activities Related to Polar Research to the Committee on Polar Research of the National Academy of Sciences mentioned four areas of activity of interest to the polar scientific community. Two of them had special pertinency to remote sensing:

1. The surveillance of the atmosphere by satellite and rockets, and

2. The satellite surveillance of the earth and its features.

The Cold Regions Research and Engineering Laboratory of the Army (now the Terrestrial Sciences Center) also has demonstrated an interest in remote sensing as applied to the polar regions. For example, its Quarterly Progress Report of the Photographic Interpretation Research Division for May 1967 describes under Earth Science Studies by Remote Sensing a project concerned with Arctic and Subarctic Vegetation Studies. Under Space Applications of Remote Sensing is mentioned a project "to improve interpretation of remote sensing imagery of sea ice" and a project "to obtain remote sensing imagery of sea ice off Barrow, Alaska."

In a paper on Glaciology in the Arctic that appeared in May 1967, mention is made repeatedly of the requirements for the use of remote sensors, both in aircraft and aboard satellites.

George Gryc of the U.S. Geological Survey, the Chairman of the Remote-Sensing Subcommittee of the Arctic Institute's Research

Committee, reported to the Arctic Institute in May 1968 that: "The Symposium was, in my opinion, very successful; and interesting and stimulating dialogue was developed.... The atmosphere scientists appear to be in the best position to use remote sensing especially from space platforms. Apparently the problem of remote sensing application becomes increasingly difficult earthward and very difficult in the deep sea environment. However, remote sensing is certainly applicable in all environments but the mode of application must be adjusted to the environment and the problem.

"Certainly the polar regions because of remoteness and the primitive state of knowledge in many fields should be prime targets for satellite-borne remote sensors. However, remote sensing from conventional aircraft, land-based, and water-borne craft can also be very useful and should be kept in mind."

Remote sensing is difficult to define exactly. In the simplest terms it means to sense something without touching it; and the sensor is an instrument rather than a human being. In passive remote sensing, the sensor only reacts to manifestation of presence, registering for instance the bark of a seal, or the light of the aurora. In active remote sensing, the sensor receives a purposely stimulated reaction signal such as a radar or sonar reflection.

Electromagnetic radiation strongly dominates the field of remote sensing; followed by sensing of body waves (atmospheric and aquatic

acoustics, and seismics); by physical and chemical sensing of emanations, somewhat akin to tasting and smelling; and by sensing of magnitude or changes in electric, magnetic, and gravitational fields.

The conference revealed clearly that communication between the developer of remote-sensing tools and the user scientists, especially the biologist, often has been less than good. A main reason has been that advanced remote sensing in the electromagnetic field has been an expensive militarily oriented development. Some of the best equipment is not yet available for civilian use. The high expense makes it difficult for the scientist to initiate development of the special instruments he needs. He generally must compromise with what is available within his all too often inadequate budget. The sophisticated electronics often requires operation of the equipment by specialized technicians, and aircraft and satellite platforms are difficult to obtain.

Here the era of the lone individual is surely essentially at an end. The initiating scientist needs a team, excellent administrative support, and sufficient time and financing. Only the hardiest will be successful in getting what they want, and at a high price in effort and frustration. In general, the main problems in remote sensing are not with the quality of the sensors, which are mostly very good, but with the choice of sensors for a specific purpose and with interpretation of the sensor output.

The choice of the appropriate sensor is often most difficult. The user must define the objects he wants to identify. The remote-sensing specialist will need to know such things as the spectral reflectivity or emissivity of the object; the object's temperature; whether or not the temperature changes with time, diurnally or seasonally; the spectral properties of the background; the medium between the object and the sensor; and the necessary resolution.

When a sensor or combination of sensors has been chosen, the question of the physical system arises--the platform, the carrier, and the recording of data on board or by transmission to a ground station. Then comes the question as to how the data output is to be interpreted. Here arises the rapidly developing and complicated problems of information handling. Decisions here feed back into the physical system, so in principle, from the very beginning, we are concerned with complex systems analysis, requiring the collaboration of at least several specialists. There is a constant process of compromise between what the user wants and what he can get with the facts and the means at his disposal.

Two things apparently are necessary if widespread use of remote sensing in the polar regions is to become a reality. More scientists, engineers, and technicians will have to go into the field of remote sensing, and funding for remote sensing must become more readily available.

Remote Sensing--Today and Tomorrow

A starting point for the substantive part of the Symposium was defined by W. A. Fischer in his opening talk. He said, in summary, that:

During the past four years the trend of research in remote sensing in the United States has been directed toward:

1. Improved repeatability of remote-sensing observations;

2. Assessment of the utility of time-change as a meaningful observation parameter, both from the standpoint of assessing rates of change and identifying objects;

3. Determination of the chemical/mineralogical composition of surface materials from remote positions; and

4. Extension of remote-sensing observations into the third dimension.

Fischer listed five "dimensions" of remote sensing: 1. the spectral dimension, 2. the luminescence dimension, 3. the time dimension, 4. the polarization dimension, and 5. the spacial dimension.

Some remote-sensing systems make use of a combination of the spectral and spacial dimensions. These include cameras, optical-mechanical scanners, and radar and microwave imaging systems. Systems making use of the spectral dimension are non-imaging in the conventional sense. They include spectrometers, radiometers, and

interferometers. The luminescence dimension is illustrated by images showing the distribution of luminescing solids produced by active systems that illuminate the scene with ultraviolet, visible, or infrared wave lengths.

Time is probably the most powerful dimension within which to discriminate and identify objects or conditions. All sensors can be used to assess change in objects with time, provided their successive records can be compared efficiently. Use of the polarization dimension involves comparison of radar images recording radar-energy returns in two planes of polarization. This has resulted in improved discrimination of man-made objects from natural backgrounds and differentiation of rocks having differing surface roughness.

Fischer concludes that essentially all potentially usable parts of the electromagnetic spectrum are under investigation. Instruments are available to sense in most, if not all, of the spectrum and in the various dimensions of remote sensing. Looking ahead, it seems likely that the increasing demands for resources and the need to manage those resources wisely will accelerate the demand for timely survey data. Likely this increasing demand for timely survey data will cause many of the current experimental systems to be placed in operational use in the near future.

Panel 1--The Ionosphere, Upper Atmosphere, and Atmosphere

PANEL MEMBERS

Keith B. Mather
Rudolph Penndorf
Morton J. Rubin, Chr.
Stanley D. Soules

Remote sensing is not concerned with the medium immediately surrounding the observational platform. The panel felt that care should be taken to keep in mind that, in addition to satellites, other vehicles and other means of obtaining data also are available such, for example, as automatic stations. The panel indicated that it planned to focus on the problems of the ionosphere, the upper atmosphere, and the atmosphere. It would explore the kinds of observations and data needed to solve the scientific problems in those environments as well as the information needed to apply the knowledge to practical ends. What is available in the remote-sensing storehouse that can lead to increased knowledge of the ionosphere, the upper atmosphere, and the atmosphere? Subjects to be explored include the possibilities of remote-sensing techniques acquiring needed data more economically, more conveniently, and integrated over both time and area without going into the field; the acquisition of instantaneous values; values at a point; and time and space averages. The acquisition of synoptic or nearly synoptic data is important.

The atmosphere

Generally, the meteorologist is concerned with the composition of the atmosphere, including trace gases, water vapor, ozone, and others. The interest in composition also includes particulate matter in the atmosphere. This general concern applies to the atmosphere of the polar regions just as it does to the atmosphere elsewhere. The polar regions are not the only parts of the world from which such information is difficult to obtain. Another example is the open oceans. The hope is that remote sensing will help obtain such information from the polar areas and elsewhere.

Information is needed especially about the boundary layers, the lowest parts of the atmosphere in contact with earth surfaces. We need to know much more about the important processes that go on there between the atmosphere and the underlying surfaces. We also need to know about the basic circulation of the atmosphere and the variation of that circulation both in space and in time. Much emphasis is being placed on this now through global-atmosphere research programs that are being conducted on an international basis. Such information is needed especially for extended-range forecasting.

The kernel of the whole problem is radiation and the heat balance, especially in the polar heat sinks. Such information is needed over all wave lengths. We need to know for example cloud-top temperatures,

surface temperatures, and the distribution of water vapor. Here the interests of the meteorologists impinge on the interests of other groups. For example, we need to know about the exchange of energy between ice and open water.

Finally we need to study the problems involved in the coupling and interaction of the processes between the atmosphere and the underlying surfaces and with the higher atmosphere.

The upper atmosphere

The consideration of the upper atmosphere was opened with a discussion of acoustic waves and their use in studies of the auroral zone. The waves are of long period--from about one second up to as much as 30 minutes. They are detected by microbarographs. Such waves are of interest also to meteorologists and solid-earth physicists. A strong source for such acoustic waves lies in auroras, especially moving auroras. Stationary auroras apparently do not generate acoustic waves as readily. They are shock waves initiated by large-scale motion of auroral forms. No acoustic waves in the audible part of the spectrum have been detected. The auroral acoustic waves are directional, and the azimuths are readily determined. Other sources of acoustic waves, and these are independent of cloud cover, include wind blowing over high ridges and volcanic eruptions.

A conspicuous deficiency in studies of the upper atmosphere has been the lack of coordination among researchers in comparing the results from different sensing devices, for instance results from satellites and from the ground simultaneously. If such coordination could be improved markedly, the results that could be derived from observations would be tremendously increased.

The ionosphere

The ionosphere is the part of the upper atmosphere in which ions and electrons affect the propagation of radio waves. In that area investigations are carried out with electromagnetic waves. There is vital need for information in this field because of the direct application to communications and other military and civil uses. In this area also a great deal more coordination is required, as was pointed out for the auroral zones earlier. The incoming particle flux that creates the ionosphere must be measured. The sun is a source of electron flux in the polar regions, but is not a dominant source, especially during the intervals of darkness. Measurements must be made from satellites. We need to know how electrons recombine with ions and how to measure vertical and horizontal motion. We need to know the electron profile and much more also. Sources of electron flux are many and variable. We must know composition and compositional changes. We must know temperatures and temperature changes. We need to know gravitational

forces, tidal forces, and magnetic and electric fields, which have been measured by the use of artificial clouds with injected ions. Apparently ionized clouds move differently than non-ionized ones. We should select certain stations and instrument them extensively. Many measuring methods exist, but their use must be highly coordinated. It is possible to separate the various parameters such as flux rates and sources and come to a better understanding. Disturbances must be forecasted for communication purposes and other applications. We need to know what circuits will be open, at what times, and what frequencies.

Instruments and techniques

Instruments and techniques are available now to measure a whole class of parameters of features of the atmosphere, upper atmosphere, and ionosphere. Within the next three to five years instruments and techniques probably will be available to measure a whole additional class of parameters. However, such instruments are not yet available for installation in spacecraft.

Thus far the TV camera has been the workhorse in this field. TV cameras in spacecraft record cloud cover and cloud type daily over the world. Ridge and trough lines can be located as can fronts and storms. Sequences of pictures reveal cloud motion. The records are distributed to weathermen and are used to improve predictions and

to fill in areas of sparse data, such as over the ocean. From cloud shapes, striations, and plumes can be inferred direction of movement and estimates of wind speed.

Satellites in geosynchronous orbits now over the equator give cloud cover over large areas every 23 minutes. TV cameras also are useful for recording and studying ice distribution and movement. Another device is the cloud-altitude radiometer which gives the altitudes of cloud tops. Still another that is expected to be in operation soon is an infrared spectrometer that will work in narrow spectral bands of CO_2. The results will yield vertical-temperature profiles of the atmosphere, probably accurate to 1 1/2°C. to 2°C. Therefore, information will be available on the temperature structure of the atmosphere from regions for which data now are not available.

In one and a half to two years a spectrometer probably will be available that will look at CO_2 and also at water vapor. Thus the content of water vapor can be determined. By looking through spectral windows, temperatures can be measured of land and sea surfaces as well as cloud tops.

One of the problems thus far is that radiometers have deteriorated in space, presumably through the action of the sun's radiation on the component materials. Radiometers now are being devised with on-board calibration. With such radiometers heat-budget measurements can be made.

Space photography from manned satellites has proven useful. Such photography has been obtained from both the MERCURY and the GEMINI programs. It will be continued in the APOLLO program.

Other instruments have been considered and other techniques. For example, what can microwaves do? It should be possible to make temperature soundings, measure surface temperatures, and observe sea states. The measurement of the solar constant is of interest, and this has not yet been done outside the atmosphere.

Those viewing the atmosphere from above are able to capitalize on the difficulties of those who are trying to look at the earth's surface from above. Therefore, the use of remote sensing in the atmosphere and ionosphere is rich in potentialities. About five parameters may be considered pertinent:

1. Variation of the amplitude of the radiation with wave length;

2. Variation of the amplitude of the radiation with position, including shape information, such as shapes of clouds;

3. Polarization of radiation;

4. For those sensors that are coherent, the coherent sensing of differences in phase over different path lengths; and

5. The variation of the above parameters with time.

In regard to time there are in general two kinds of effects: slow-time effects by time-lapse photography, generally dealing with minutes,

hours, or days; and fast-time effects, for example the determination of cloud speed by radar.

There is a long list of interactions of radiation with the atmosphere, and many of the interactions are not used yet in remote sensing. For example, perhaps a proton accelerator could be pointed up and would produce an ionized column through which it would be possible to discharge lightning from clouds in a semi-controlled fashion. Other possibilities include study of the scattering and absorption of ultraviolet by ozone, the scattering of visable light, auroral scattering, and scattering of infrared by CO_2 and H_2O. It has been suggested, for example, that a high-power laser pointing up could heat a narrow column of air for a few hundreds of feet so that it might be observed by infrared in order to indicate wind velocity. The infrared from about 20 microns to 1,000 microns is relatively unexplored. In that area relatively insensitive sensors and weak sources are handicaps, but improvements can be expected within the next few years.

There is plenty of interaction to serve as a basis of measurement in the passive microwave band. Among these are absorption by oxygen, rain-drop and snow-flake backscatter in the active radar region, integrated electron density, and interactions in radiofrequencies, both high and low.

When phenomena are sufficiently complex, processing and decision making must be automated at least partially. This leads into the field

of pattern-recognition technology, for example, as applied to spectral distribution.

Progress already is being made in the drawing of synoptic ice charts and snow charts from satellite photography. This has been practiced especially in the area of the Great Lakes and the St. Lawrence estuary. Sometimes it is possible to see ice cover and snow cover through as much as 5,000 feet of stratus clouds. More international cooperation is needed in the field of atmospheric sciences and remote sensing and especially in the polar regions.

Panel 2--Physical Oceanography

PANEL MEMBERS

Albert W. Biggs
Moira Dunbar
Kenneth Hunkins
Norbert Untersteiner, Chr.
Walter I. Wittmann

Although the subject of Panel 2 is "physical oceanography," about 90 percent of the physical oceanography in the polar regions is related to sea ice. The first problem of the physical oceanographer in the polar regions is the extent of sea ice on a global scale. This includes its extent both in the Arctic and in the Antarctic. Secondly, and subject to much controversy, is the area of open water within the ice-covered area. Estimates range from as low as 0.2 percent to as much as 10 percent. The amount of open water is important because

heat exchange over open water is at least two orders greater than over solid ice. Thus the more accurate the estimate of open water within the ice-covered areas, the more accurate the heat-budget estimates will be.

More needs to be learned about the morphology of sea ice. This includes such items as its configuration, the frequency of pressure ridges, the size and directions of pressure ridges, and the shape of the underside of the ice. Only one uplooking submarine profile is available across the Arctic Ocean. The radiating-surface temperatures need to be known of snow, ice, and open water.

The albedo question is as controversial as the open-water question. Measurements of albedo from the ground, from aircraft, and from satellites simply do not agree. Frequently albedo measurements from satellites appear far too low. The lack of consistency between such measurements needs to be studied and resolved.

More knowledge is needed on the movement of floating ice. This involves both wind and water stresses on the ice and how the ice reacts to those stresses. The thickness of polar floating ice is very irregular, as anyone knows who has tried to get an average thickness by drilling through the ice. Remote sensing would be very useful in this respect if it could give average ice thicknesses.

Of the points just mentioned, areal extent is the simplest

requirement of ice reconnaissance. The standard method thus far has been visual observation from ships, the shore, or aircraft. This has been relatively unsatisfactory, and remote sensing for routine reconnaissance is very helpful. To some extent sample photographs have been used but not as much as they might be. Radar observation can identify ice edges under clouds, and closed circuit TV is used in some instances. However, meteorological satellites now to a substantial extent give the big overall picture which was not available before. This is very useful, but it is still not the complete answer. Meteorological satellites however have given the scientist a new dimension of observation.

The U.S. Navy has been observing ice all around the North American continent and along the Asian continent as far west as about 100 miles from the New Siberian Islands. The density of ice cover and the nature and extent of ridges and similar features are of interest both for their scientific value and for their use by surface ships and submarines. When it is remembered that the ridges generally extend to about 16 feet below the surface and sometimes to as much as 150 feet below the surface and that the depth of a part of the Chukchi Sea is between only 20 fathoms and 30 fathoms, the importance to submarine operations is obvious. Infrared images have proved useful in the dark times of the year. Radar, including side-

looking radar, has been useful when the surface is covered by clouds. A passive microwave system is useful for identifying the ice edge. The limitations of some of the methods at the present time are those not only of instrumentation but also of properly equipped aircraft with sufficient range. Radar imagery should be stressed because of the requirement for obtaining information through clouds and because of the need for sequential data over small areas. An automatic buoy-type telemetering system has been devised and may prove useful.

Thin ice is interesting scientifically because of heat-budget considerations. The energy exchanged between the sea and the air changes markedly even with a very thin ice cover. Such a thin ice cover is of little interest operationally to a ship or to a submarine. Work needs to be done in this area.

Turning now to open-water physical oceanography, there is need to know much more about the state of the sea in the areas that border on the ice-covered areas, as for example around Antarctica and in the Bering Sea. The Bering Sea is a case where the ice cover over a large part of the sea is seasonal only. The first problem in regard to the open ocean is to know more about the motion of the water. The currents are not known in any detail yet. First we need to know more about the currents at the surface. In this respect the oceanographers are behind the meteorologists who know more about the atmosphere than oceanographers

know about the open ocean. We do have a fair idea of some of the surface ocean currents over long times and large areas, but we are deficient in knowledge of currents in small areas and over short intervals of time. Remote sensing has a great potential in this respect, at least as regards surface motion. This may not be true at depths because electromagnetic waves do not penetrate far below the surface. One of the problems, of course, is markers, the motion of which can be tracked and recorded. At least in part we can use recognizable pieces of ice for this purpose.

Thus far such studies have involved usually only one or two, or perhaps as many as four, separate pieces of ice in the water, but what is really needed is an array over areas of hundreds or thousands of square miles monitored for a limited time so that studies can be made of horizontal eddies and interaction of ice floes. Consideration might be given also to studies in both the Antarctic and the Arctic of strings of active or passive buoys stretched across the current so that the buoys could be tracked for relatively long periods of time, perhaps a year or so.

Surface currents are primarily wind-driven. Of interest also are convective currents that are driven by differences in temperature and salinity. In this field we have very sparse information. One of the prime problems is the inflow and outflow of the Arctic Ocean

through its various openings. Of particular concern, an area of particularly sparse information, is the flow between Greenland and Spitzbergen. If a string of buoys could be stretched across that current and tracked to say the region of Iceland, it would be most useful.

A Navy satellite-tracking system on T-3 makes it possible to get a fix for T-3 to within 0.1 or 0.2 of a mile, perhaps as often as every twenty or thirty minutes when, as is now the case, there are somewhere between two and four satellites in orbit. This is really more detailed and accurate than is necessary for the purposes of T-3 but is the sort of accuracy that is required if we are going to learn much about smaller-scale motions in the polar oceans.

Subsurface currents are more difficult to study. Electromagnetic waves are of little use because they do not penetrate far. Sound waves are more promising. In a sense we have done remote sensing in the ocean for a long time through echo sounding, for example. More recently we have been doing seismic profiling from the ocean floor to depths of several kilometers under the sea floor. Acoustics also give information on the deep-scattering layer that is found in the Arctic Ocean as well as in other oceans. Not much is known about that layer, but it appears to be biological, although the responsible organism is not known.

Deep currents can be tracked by acoustic fixes on subsurface buoys such as those developed at Woods Hole and called the "Abyssal Whistle".

It emits a signal every few minutes and could be used in the Arctic where subsurface currents are poorly known.

Out of the discussion came one outstanding problem. That is the requirement to be able to measure the quantity of ice in a given area, especially when the ice is very thin. Apparently infrared techniques are approaching the place where it may be possible to do this, especially when the platform used is an aircraft rather than a satellite. Apparently however infrared techniques will have difficulty with distinguishing narrow open leads because the system tends to average out and not distinguish such small features. One of the problems with the use of infrared sensing, of course, is that the sensing is hampered to a certain extent by clouds. Some of the other complexities of the ice itself makes remote sensing of ice, especially salt-water ice, extremely difficult. Some of these factors are the water content, the salinity, the snow cover, and the various layers piled on each other.

The scientist is concerned with three aspects of remote sensing of sea ice:

1. Imaging that gives a gross image of sea ice conditions;
2. Scatterometry; and
3. Altimetry, both for profiling and for the determination of ice thicknesses.

Each of the above involves backscatter in regard to surface roughness, the frequencies with which we scan the ice, and the polarization. In regard to polarization we are dealing with horizontal polarization, vertical polarization, and cross polarization in both cases. The angle of incidence is of interest, both for imagery and scatterometry, and the dielectric properties give an indication of the subsurface structure of the ice. In the radar mapping of ice sheets, important considerations are crevasses, ice slopes, and relief aspects. Some of the problems have to do with distinguishing snow from ice and differentiating different types of ice. Scatterometry is useful in the remote sensing of sea states. Backscatter is higher from rougher seas. Smooth ice gives very little backscatter. Altimetry is relatively inaccurate, probably to within only perhaps fifty meters, and therefore is not too useful in regard to remote sensing of sea ice.

In summary, three sensing devices were mentioned as means of studying differences in the characteristics of ice and differences in thickness. We need to develop additional frequencies and to test them by additional flights over sea ice.

Panel 3--Biological Oceanography

PANEL MEMBERS

Paul M. Maughan
John L. Mohr
Carleton Ray
John C. Sherman
Norman J. Wilimovsky, Chr.

The biological oceanographer has a more difficult task remote-sensing wise than does either the scientist interested in the atmosphere, the upper atmosphere, and the ionosphere or in physical oceanography. It is necessary for the biological oceanographer to sense through the water and to learn about:

1. The physical and chemical parameters of the water;

2. The biological features such as productivity of types and associations; and

3. The environments within the organism, as for example blood pressure.

The marine biologist is generally imcompetent to work with remote-sensing matters. He recognizes remote sensing as a tool, but he must keep it in perspective and use the tool selectively. Large marine animals generally are interface animals. They live part of the time in water and part of the time in air. Little is known about how many individuals there are or even how many species. Little is known about their underwater behavior. The marine biologists are far behind the terrestrial biologists in this respect. More must be

learned somehow about underwater behavior. First the presence of animals must be determined, second their physiology, and third their natural history. The main difficulty really is the problem of following the animal. Thus far the best success in this respect has been done by a man from a ship with a pair of binoculars. This is in a sense remote sensing. The maximum penetration of water for viewing is about 300 feet. Apparently there is no spectral window of one or a few wave lengths that are likely to allow penetration of much farther than 300 feet. It is easier to view an animal from below by looking up at a light background than from above by looking down at a dark background. Sensing of animals with electromagnetic devices has some potential but is not very hopeful. Furthermore, thermal sensing is not likely to be very useful. Remote sensing will not "see" the animal; at best it will "see" one or more phenomena associated with the animal. From such sensing we can learn or infer a good deal about the animal, and this is true whether the sensing of the phenomena be by chemical detection, sonic detection, heat detection, or otherwise. But of all of these, by far the most important in detection of marine animals is sound. It is possible to listen passively to an animal and learn a great deal about it providing we know enough about the nature of the animal. It is possible to listen in the Antarctic in October and hear many Weddell seals, but none are heard if the listening is done in January. This does not mean that the seals

are not present in January but that they are not making a noise. Therefore, we must know the natural history.

The planting of devices in large marine animals for active sensing has thus far resulted in a long series of failures. The animal resents the attachment and generally is able to get rid of it. Also it is expected that, if a device could be planted so that it could not be removed, it might interfere with the animal's behavior. Some possibility exists for planting a recording device in an animal and then recovering the device for information. Additionally devices might be implanted that would report information at times when the animal surfaces. Thus far however none of these procedures has worked. Furthermore, even if the device could be employed in such fashion successfully, it would tell about an individual and not about a whole population. The cost and effort of getting sufficient data on whole populations would be exorbitant. Physical parameters need to be found that can be sensed effectively. Marine mammals cannot be studied adequately from the surface; therefore, remote sensing would be of great use if it could be employed. It would be most difficult, for example, by remote sensing to locate the Antarctic convergence, say monthly, or to spot individual whales. Even if a means could be devised to sense large numbers of individuals economically, some method would have to be found of identifying individuals or only mass movement would be determined.

The visibility of animals depends on their spectral reflectivity and emissivity and on the background in which they are embedded. Photographs can show fish, or the turbulence around them, or near the surface can show also shapes of schools. In some instances oil slicks look like schools of fish. Sometimes slicks caused by fish oil break up into droplets whereas slicks of petroleum do not. In shallow water fish can sometimes be identified by their shadows on the bottom. Photographs from space may show upwellings where there is rich bioproduction. What is needed are subsurface "satellites." Widespread use of submarines is too expensive, and furthermore, submarines are not generally available. A possible solution is a mother ship with instrumental platforms such as torpedoes or small submersible craft. These might be programmed to follow a planned trajectory and return to the mother ship. Significant areas could be covered by a substantial number of preprogrammed submersibles. Of course, there are some difficult engineering problems, and also there is the matter of the choice of the most appropriate instruments. A good case can be made for giving up trying to look under the water from above and to getting down into the medium and finding out what features there, in that environment, can be used for tracking. A "submarine satellite" is a hopeful objective.

One reason that marine biologists have not advanced farther in this subject is the insufficiency of research and development funds to obtain

the engineering help that is needed. Also marine biologists have not sufficiently expounded their needs. Some of the possibilities for studying animals underwater might be their bioelectricity, their odor, or their study by fine-resolution sonar. Perhaps it would be possible also to follow the turbulence of schools of fish. If this could be done, much could be learned about behavioral patterns that would permit better use of surface information.

Emphasis was given to the value of observation from aircraft and satellites for gathering broad pictures over large areas through the acquisition of synoptic data. It was recognized that such sensing is only complementary to the gathering of data by other means, and it was regretted that such sensing apparently is not fully applicable to sensing below the surface of water. It was pointed out that the National Council on Marine Resources and Engineering Development has issued a brochure on the pursuit of oceanography from satellites.

Finally attention was directed to the fact that certain environmental parameters can in some ways be used as keys to the study of species. Mentioned in this connection was the summer flow of arctic rivers, the relationship between food supply and the distribution of species, and the position of the ice margin and its fluctuations as related to animal populations. However, in studying individual species the main evidence appears to be underwater and must be obtained in the water environment.

Panel 4--Earth Resources, Geomorphology, Glaciology, and Permafrost

PANEL MEMBERS

George Gryc, Chr.
Marvin R. Holter
Mark F. Meier
J. C. F. Tedrow
A. L. Washburn

Bedrock geology

Starting first with some of the problems of bedrock geology in the polar regions, it is obvious that remote sensing can be of great use. Remote sensing is not new in the earth sciences. Many of the geophysical tools that have been used in geologic mapping for years are remote sensors. From ground-based sensors the earth scientist of long ago moved to the use of airborne platforms with the development of aerial photography, the airborne magnetometer, and some other sensing tools and methods. Now the trend is toward sensing from satellites with the development of new hardware and new techniques. To a certain extent earth scientists seem not to have kept sufficiently abreast of these developments. As a result there may be in some respects a certain apathy among geologists as to the use of remote sensing from orbital platforms. One of the first problems is what can be done now with the techniques that we have and what better techniques can be expected for the future.

Under the assumption that remote-sensing satellites are placed in polar orbits, the geologist needs to know something about the instru-

mentation that can be put aboard for use in making geological observations. Modern bedrock geology involves the identification of various types of rock, their distribution, their various characteristics, their structure, and other features, as well as the interpretation of what those rocks may mean to man in the sense of mineral resources, hazards such as earthquakes and landslides, and land use. Furthermore, a geologic map is more than a two-dimensional interpretation; it also carries much information into the third dimension. Various types of observation are used in the compilation of such maps, and remote sensing is especially suited to some of them. Of particular interest perhaps is the potential of remote sensing in reconnaissance or exploratory geologic mapping as distinct from more detailed mapping. Such reconnaissance and exploratory mapping is especially important in the polar regions, for example northern Alaska, and is needed for obtaining the broad picture and for the identification of targets for further, more detailed exploration.

Soils

The study of arctic soils started in Spitzbergen about fifty or sixty years ago. The distribution of soils across the central part of the Eurasian continent is now reasonably well known. In fact this is true almost all the way across the northern Soviet Union, except that in the eastern Siberian highland the coverage is rather spotty. More

work needs to be done in Spitzbergen also.

In regard to North America, some of the largest blank areas are in northern Canada. However, some good work has been done in the Mackenzie River basin and here and there in the northern islands. A little work has been done at a few places in Greenland. Northern Alaska is fairly well known as regards soils distribution, in fact it is probably better known than central Alaska. In considering the use of aerial photographs in soils work, it should be emphasized that on aerial photographs the soils are not seen. Seen only is the plant cover over the soils. It follows that photographs in soils work are of greater use in the Arctic, especially in the high Arctic, because the plant cover is generally less. A famous Soviet scientist has said that if we know certain facets of climate, plants, and rocks, we can detect soil morphology. That statement has held up pretty well. It follows that aerial photographs can be used with a minimum amount of field work in the Arctic, especially in the high Arctic, to gather a great deal of information on soils rather quickly and on a circumpolar basis.

Sequential aerial photographs taken at intervals such as five, ten, and fifteen days would be of great interest in soils work in the polar regions. From such photographs moisture changes could be detected, and a good deal could be learned about temperature ranges. Such photographs also might be useful in the study of salt-crust formation and soil

texture, including such things as sand, gravel, and clay content. Soils studies could be integrated with the accumulation of data of a more general nature from high flying aircraft or from satellites mostly from photographs, either conventional photographs, pancromatic photographs, or infrared.

Glaciology

Glaciology is the study of snow and ice. Glaciology therefore is not limited to glaciers. Snow and ice cover most of the polar regions most of the time. Furthermore, the seasonal snow cover changes rapidly at certain times so we must look at short intervals. Glaciologists have long been interested in remote sensing. Visible images from space apparently depict mostly clouds and snow and ice. Therefore, glaciology already is deeply involved in remote sensing. Furthermore, it so happens that four or five of the main problems in glaciology today happen to be especially susceptible to solution through remote sensing. Here are a few of those problems:

1. Dynamics of sea ice. The dynamics of sea ice has both meteorological and rheological aspects. Meteorologically sea ice is important in the study of the world's energy balance. The ice itself is a product of the energy balance at a given time and place and therefore has important rheological aspects. The transfer of energy from the earth to the atmosphere through the sea-ice cover is said to be a

function of the leads that are present. The deformation of sea ice that causes the leads is poorly understood, and much more information should be obtained. Furthermore, measurements at any one point essentially are useless. Sea ice consists of thin sheets essentially without strength and with some heterogeneous masses and ridges with considerable strength. This is a situation that can be studied only by remote-sensing techniques because it is necessary to determine average properties over large areas. This sort of a problem can be approached by dropping little beacons or radar reflectors and then using images obtained by satellite or otherwise to study motion fields and distortion patterns. In order to make this sort of study effectively, we should develop better methods of seeing through cloud cover.

2. Snow hydrology. Snow is a hydrologic resource of substantial economic importance. In temperate latitudes the cash value of snow is enormous. Snow has some detrimental effects, like impeding traffic, but it also stores water for future runoff that can be predicted. In the future civilization must learn to manage the snow resource by either accelerating or retarding melting as may be required. The measurement of snow cover at a point is very easy and can even be done automatically. However, such measurements have little value, and the real problem is to measure the snow cover over large areas. The pattern of snow cover is extremely irregular and furthermore varies rather rapidly with time.

We have no good method now of distinguishing between snow and clouds by remote sensing. Snow usually occurs in cloudy areas. One possible method of distinguishing that might be developed is pattern recognition based on the fact that clouds move and snow does not.

Of special promise in the study of snow cover is passive microwave sensing. Such sensing is concerned with the thermal emission of the snow or the ground below it. The situation is complicated because many things affect the thermal emission, such as grain size and surface roughness. Hydrologically those factors are unimportant. The important hydrologic parameters are density, temperature, thickness, and water content. All of these also affect the microwave emission. With passive microwave it is possible to look at the snow with many different frequencies simultaneously, and at each frequency it is possible to make the study with two polarizations. With each frequency and polarization a variety of viewing angles can be selected. The method contains so much redundancy that, in spite of the apparent complications, it just may be possible to sort out the variables.

3. Energy balance. Energy-balance studies are useful in relating snow melt to weather and also in studying the relation of glaciers to climate. In such energy-balance studies there exists the old problem of some means of extending points of observations to areal observations. Passive microwave methods and thermal-infrared methods appear to hold some possibilities in the future.

4. Mass balance of icecap. The fourth major problem in glaciology is the determination of the mass balance of the major icecaps. Oceanography seems to indicate that sea level is rising, and hence the icecap is supposed to be melting. Glaciology however appears to indicate that the volumes of the icecaps are increasing. The big uncertainty in the appraisal of the mass balance of the icecaps is the determination of the loss by icebergs from Antarctica and from Greenland, the difficulty of determining net accumulation over large areas, and the difficulty of measuring melting under the floating ice shelves. For those kinds of problems remote sensing appears to be the only practical solution. For example, by repetitive determination of the glacier icebergs over large areas by remote sensing at selected intervals of time, it should be possible to measure the iceberg flux and hence get a fair idea of the amount of wasting by that process. Also it should be possible to measure the flow rate of ice sheets by remote sensing and the thickness by radio sounding.

Development of remote-sensing techniques

Some other types of observations can be done best by remote sensing. Soil moisture, for example, is important and can be measured by passive-microwave methods. Water pollution also is a problem and perhaps can be sensed remotely by some luminescence method. The freezeup and breakup of arctic rivers also could be determined by remote sensing.

The types of problems discussed above need devices that will operate over large space scales and rather small time scales, will see through clouds, and will yield to investigation by pattern recognition. The potential avalanche of remote-sensing data should bring a reevaluation of research philosophy and research techniques. It should result in a reexamination of data needs, and it holds tremendous possibilities for world-wide investigations, such for example as an appraisal of the world-wide snow pack.

Remote-sensing methods have long been of use in topographic mapping and indeed in structural geologic mapping and geomorphologic interpretation. It seems likely that remote sensing can be useful in working on some permafrost problems. We need methods of detecting the presence or absence of permafrost. We need to know its thickness and the thickness of the active layer. We need to know its temperature and the temperature gradiant within the permafrost zone. We would like to know the soil type or the type of bedrock and the ice content and distribution of ice through permafrost. We need to know about the presence or absence of unfrozen zones in the permafrost if present and their size, shape, and distribution.

Remote sensing might be especially useful in tracing and studying emerged strand lines. Such studies, of course, would give information on relative changes of sea level and on the tilt of the land. Observations

of strand lines by remote sensing should be especially suitable in the polar regions because of the general scarcity of vegetation. We also need information on the tilt and direction of tilt of the strand lines within a reasonable limit of error. Remote sensing might also be applied in a different way in regard to studying solifluction and other motion of surface materials. Perhaps free bodies could be emplaced below the surface, say a meter or so, and then could be followed by sensing as an indication of the motion of materials near the surface. This sort of a study might be called micro-remote sensing.

In general, remote sensors are in a more advanced stage of development than is the knowledge of how to use them. We cannot look forward to any great improvement of sensitivity of sensors. The theoretical maximum of sensitivity can be calculated throughout the electromagnetic spectrum, and such considerations indicate that most of the present remote sensors are very good indeed. Furthermore, in many of the applications of remote sensing, additional sensitivity would not be of much assistance. Therefore, sensor research is moving toward improved interpretation rather than improved sensors. Part of the task of improved interpretation is learning how to distinguish contrast between the things of interest and the things that are not of interest. This requires mathematics, physics, and engineering-type skills. Another type of interpretation is the matter of the significance of the contrasts that can be recognized. What do those

contrasts mean or what can they mean to geologists, geographers, and other users?

Except in the sea electromagnetic sensors seem to be the most interesting ones. Of course, there are other types such as gravity sensors, electrostatic-field sensors, magnetic-field sensors, and so on, but these tend to have short range. We really know remarkably little about what have come to be called "signatures", that is the aspect of radiation that distinguishes one material or one phenomenon from another. The bag of remote-sensing tools is fairly rich and in many cases contains something useful if the remote-sensing specialist and the user can get together. Improvement in sensor systems will mainly be in the use of the components in novel ways. In general, the remote-sensing specialist cannot answer user questions unless he knows the spectral reflectivity and emissivity of the materials of interest.

Panel 5--Terrestrial Biology

PANEL MEMBERS

William S. Benninghoff
Lawrence C. Bliss
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Frank A. Pitelka, Chr.

Remote sensing is very useful in yielding information on the distribution of major vegetation types and even on species. Thus far most such information has been gained with the use of aerial photographs. A

great deal of ground truth already is available on plant distribution. But we need methods of learning about large-scale regional estimates of production in both time and space. Remote sensing is generally more applicable to plants than it is to animals. For large, warm-blooded animals we need information on numbers, on distribution, and on movement. We need to learn also about the parts of the physical environment that are pertinent to the production of plant and animal life. We need to monitor areas over extended periods of time in order to observe diurnal and seasonal changes. In remote sensing of plants, study of them is important both in relation to the diurnal cycle and to the seasonal cycle. A good deal of spectral structure exists as a basis for the identification of plant species and for the estimation of the health of plants. The great variations in polarization are not yet well understood. For example, for some unknown reason, sugar beets show up strongly at a special wave length.

The aerobiology program of the IBP includes the study of atmospheric dispersal of biologically significant materials such as spores, pollen grains, bacteria, viruses, small insects, submicron organic particles, and gases such as CO_2, SO_2, and ozone that are critical to biological functions. The polar regions have distinct aerobiological characteristics. For example, there is a smaller input of such materials as spores and pollen. There are less methane and CO_2 produced. In the polar regions the troposphere is thinner and less active, and therefore the biological products are not stirred up and spread around as much as at lower latitudes. For that

reason the polar regions are good areas in which to make base-line studies of such biological emanations. Particulates in the polar atmosphere can be studied by remote sensing that detects the scattering effects of gases such as water vapor and CO_2. Water vapor controls plant transpiration rates and the range of the activity of some animals. The CO_2 content of the atmosphere near the ground is critical, and it varies both diurnally and seasonally, thus affecting the rate of photosynthesis but, more importantly, regulating respiration and other processes of both plants and animals. There is a flush of CO_2 emission from the tundra at the time of the snow melt presumably from microorganisms and from larger plants before the process of photosynthesis begins. Ozone, even in small excess over normal, disturbs green-leaf functions and inhibits fungal and bacterial growth. SO_2 in the atmosphere, because it combines to form sulfurous and sulfuric acid, can be very damaging to plants and animals. Furthermore, pine forests exhale terpenes which form submicron particles under the influence of ultraviolet radiation.

The Arctic is a good place for experimenting with remote sensing in biological investigations. The vegetation is simple in structure, there are fewer species, and the patterns are less influenced by man. Furthermore, there are larger, relatively uniform areas. There may be some possibility of using remote sensing for measurement of chlorophyll production in different kinds of plants. The rate of production

changes from south to north. Furthermore, the diurnal heating of the ground depends in part on the nature of the plant cover, and this is amenable to study by remote sensing. Attention should be given also to observing areas at the most appropriate times of the year. For example, in the fall when there are many color differences, the distinguishing of certain types of vegetation could be much more readily done.

The main animals of concern in the Arctic are the large mammals such as the caribou, the musk ox, and the polar bear. The caribou feed on lichens in the winter. In some parts of the Subarctic, the populations have dropped to less than 10 percent of their former numbers. The Lapps manage caribou or reindeer by herding them from one range to another. If left alone, they can over-browse their range, and recovery is very slow, sometimes up to a century. Thus it would be desirable to know the range conditions in order to manage the animals. Remote sensing can be used in counting and tracking animals, especially by infrared emission. It might even be possible to separate, for example, musk oxen from caribou by having a sufficient knowledge of infrared emission characteristics.

The polar bear is an animal of the sea and wanders great distances over the frozen ocean. Polar bears can be monitored by the use of radio transmitters on collars. The monitoring could be by satellite. It should

be possible to interrogate animals from satellites for temperature, heart beat, and position. One satellite could monitor more than 100 animals and could give a fix on perhaps 50 every two hours. Each bear could give six items of information by interrogation. A code signal would identify the individual animal. In fact, we do not know how many polar bears there are. Estimates range from 20,000 to in the order of 1,000,000.

Birds also are of great interest. Remote sensing might be adapted to measuring at least large colonies of birds that sometimes contain several millions of individuals. It was pointed out that a single bumblebee has been tracked by radar.

One of the major problems, of course, is the matter of distinguishing between species of large mammals by remote sensing. Conceivably remote sensing might be adapted to such distinctions if the reflectivities and emissivities of the animal species differ enough. Another approach is that if the various species of animals do not mix, the identity of a herd can be preserved by remote sensing if it is seen sufficiently frequently.

Small animals like lemmings cannot be seen at any considerable distance by present day remote-sensing techniques. The growth of a lemming population is mainly under ths snow during the winter, and a technique that would sense such animals under the snow would be very

useful indeed. It is unfortunate that the prospect of such sensing at the present time appears rather poor.

Biologists in the polar regions are much concerned with the stress of cold on organisms. In order to get at that problem, there has been a very substantial effort in micrometeorology. Perhaps remote sensing could help here by having infrared cameras or other means of sensing measure the local-energy environment in a faster and more satisfactory way than by such conventional methods as making numerous observations or setting out instrument packages. Perhaps it is expecting too much from remote sensing to hope that it could deal with the thin layer near the ground or under the snow in which so much of the life processes of various organisms go on.

With experimentation, comparison with ground-truth areas, and otherwise, it may be possible to use remote-sensing methods as a way to measure the total biomass of areas of different vegetation types like forests, grasslands, and tundra. Not much has been done yet along this line.

Would it be possible to measure the energy emitted by a colony of birds, for example, and from that measurement of energy attain some idea of the size of the colony? That sort of a problem is possible, but it cannot be answered explicitly.

Radiation sensors can measure warm bodies under a canopy such

as a forest canopy. A good deal of the radiation gets out through the canopy. However, the identification of different kinds of animals under a forest canopy does not seem very hopeful at the present time. Under appropriate conditions animals can be detected a long distance downwind with such sensors as "bio-sniffers". For some time to come the sensing of animals probably will have to be done from rather low-flying aircraft rather than from satellites. The degree of resolution is such that it is simply impractical to expect sufficient resolution from bodies orbiting as high as satellites. Again it is emphasized that remote sensors are simply additional tools. They cannot be expected to replace conventional methods of research but only to give additional information that can be used along with information obtained in other ways. Emphasis must be given to the time of day and time of year that the observations are made. The contrast sometimes appears for only short intervals during any 24-hour cycle. It is probably more than a decade away for us to expect to be able to put platforms in orbit that will sense birds or other very small animals.

Panel 6--Applications to Development

PANEL MEMBERS

Max C. Brewer
Ernest H. Lathram
R. E. Lenczyk
James H. McLerran
L. O. Quam, Chr.

In considering the applications of remote sensing in arctic research, it is desirable to learn something about the programming of satellite platforms and how individuals or groups can go about capitalizing on the opportunities that exist for making remote-sensing observations from satellites. How does one go about getting a research program on a satellite? The earth-resources program in the Office of Space Science and Applications of NASA is working on a time schedule for earthward-looking, high-resolution systems. This year NASA planned an APOLLO-applications flight with 14 experiments, including metric cameras and meteorological experiments. NASA also requested permission to let contracts for long-life TV satellite systems with high-resolution cameras. They were disallowed for the coming year for budgetary reasons and for more justification. However, the component work will continue, and space-hardened NIMBUS TV cameras with 800 lines should be ready by 1970 and with 5,000 lines a year later. This should give pictures with 100 feet to 200 feet ground resolution with altitudes of around 500 kilometers, and the pictures might show areas 100 miles on a side. It would take pictures on demand and presumably would start out by taking pictures of areas that are well known in order to get correlative data. NASA has been advised by many study groups. Some method of getting film return has been recommended. The film could be used directly for mapping purposes on scales of from 1/100,000 to 1/250,000. There is at present no plan for film return, and

the chances are that film will be returned first from manned flights. The prediction is that the earth-applications program will not get in full swing until after the first landing on the moon, which latter program takes first priority.

NASA now has two instrumented aircraft and is getting a third for higher altitude work. NASA is transferring funds to other departments like Agriculture, Interior, and Commerce, and they are proceeding with instrument-development programs. The Interior Department has a program in geography and is getting into the mineral-resources picture also. Within Interior, the Geological Survey is the coordinator. The Department of Agriculture also has an in-house group on satellites. The emphasis at the moment is on data handling and economic cost benefits. Justifications should be made for earthward-looking, high-resolution systems for scientific purposes.

The Navy now is attempting to go into mesotype studies. Two systems of instrumentation now allow positioning with sufficient accuracy to do this. One system involves an instrument package that is set out on the ice, and it is positioned to within two to four kilometers by way of the NIMBUS satellite. The package also can gather data and telemeter them by way of the satellite to Clear, Alaska, from where they go to Goddard Space Center. The other system is the geoceiver which should be ready in two years. It will be used in connection with a geodetic-

satellite system. The system will permit a relative accuracy of approximately 10 meters over 100 to 200 kilometers.

Still another system is an automatic station that can be placed on water or elsewhere. It is being developed by the Stanford Electronics Laboratory with funding by the NSF. Such a station can be placed in the polar regions; snow presents no difficulties. It can transmit data from as many as 50 experiments by way of a satellite. There will be an on-board computer that will eliminate unwanted data and can be used to restructure experiments. Data compression will be used, and based on experience with sensors, no difficulties are anticipated. The one constraint is power.

Biologists should be encouraged by the new microelectronics that will allow for the tagging of animals with very small packages indeed. It was stated that it would be almost like putting a postage stamp on a whale and mailing him wherever you wish. The importance of interpretation was emphasized. Data are not used fully unless properly interpreted. There may be more room for improving interpretation than there is now for improving data acquisition. For example, there is room for improvement in interpretation of the old process of studying ordinary aerial photographs. First must be selected the characteristic elements to be studied. In the case of soils, for example, from engineering aspects, land form is the first important element. Land forms must also be studied

in respect to the surrounding areas. Other important areas are type and density of the drainage system, gulley shape, erosion characteristics, and slope changes. All of these have subtle features that leave room for improvement of interpretation. Vegetation is often a limitation in the study of soils with the use of aerial photographs, but under some circumstances the vegetation obviously can be of assistance in soil identification. Phototones need to be studied carefully. They are the easiest characteristic to measure, but they can be a source of misinformation. Air photographs sometimes are poor for soil studies because they were taken with filters that eliminate some of the characteristics that need to be observed. Photographs in the blue end of the spectrum sometimes are the best for separating rocks but are not very useful for identification of soils. New and better films and emulsions are now becoming available. Color photography has many advantages. Infrared imagery can be a very useful tool, but before it is used, some of its limitations should be understood. It is strongly environmentally controlled as by diurnal changes in temperature, such things as wind shadows, and cold air flowing down a slope.

Radar imagery in the Arctic is a useful tool. From it we can get the year around distribution of sea ice and also distinguish to some extent between ice of different ages. With short-pulse radar it is possible to measure the thickness of lake ice accurately from less than an inch at least to as much as nine feet.

The aerial photograph at the present time gives the largest amount of information per unit area. Other sensors should now be considered supplementary to aerial photography for looking at the earth's surface.

The Coast Guard is much interested in floating ice and the forces that act on floating ice. The Coast Guard has operated the International Ice Patrol since 1913, and now it operates all the U.S. icebreakers. For a long time the Coast Guard has been interested in the possibility of remote sensing for ice-patrol work. This goes clear back to a flight of the Graf Zeppelin across the Atlantic on which the Coast Guard was represented by RADM E. H. Smith. The Coast Guard has experimented with remote sensors of various types for a number of years on board the ice-patrol aircraft. Satellite ice information also has been used in the last year or two. The Coast Guard hopes to have a project aboard the first APOLLO satellite. Aircraft have largely taken over in ice-patrol work, but ships are still used for oceanography and when there are long periods of fog. Satellites are not expected to replace aircraft for this work. It would be very useful if we could observe the ice the year around, and observations from satellites by remote sensing may be of great help here. From the ESSA satellite resolutions of about 200 feet were obtained, and this was not good enough to detect icebergs. It is expected that a resolution of about 30 feet will be obtained from the APOLLO satellite, and this should make it possible to detect icebergs.

Knowledge of ice conditions is essential to icebreaker operations in connection with arctic supply. Increasingly the knowledge of ice conditions from satellite photographs is proving useful in the operation of icebreakers--for example, the GLACIER now in the Weddell Sea is making good use of satellite information. Helicopters have very real possibilities also as platforms for remote-sensing devices.

Relative numbers can be assigned to shades of gray in infrared images. The reference radiometers that will be needed probably will be available soon. It then should be possible to relate radiation temperatures of thin ice very closely to its thickness, using open water as the reference.

In studying mineral resources, it is not difficult to shift from the land environment to the sea environment in thinking because the continental shelf has the same rocks as the land and the same types of mineral deposits in the same sort of relationships. However, it is necessary to use different techniques in making studies. In such studies by remote-sensing methods in the Arctic, there are some advantages and some disadvantages. This largely arises because of the presence in the far North of permafrost. For example, in the summer time the ubiquitous water layer on top of the permafrost surface raises problems with infrared sensing. In the permafrost areas microwave sensing has many advantages. Sulfide ore deposits generate heat as they oxidize

but apparently not enough heat to show up in infrared sensing. However, there may be enough heat to show up in microwave sensing. Possibly the non-frozen areas in permafrost may be some indication of the presence of ore deposits. For example, at the bornite deposit in the Kobuk region, there is no permafrost although it is in the permafrost zone. It also seems possible that the numerous hot springs on the Seward Peninsula indicate nearby ore deposits. Those hot springs stand out clearly on both infrared and microwave images. Microwave also is a useful tool for measuring the snow pack. It is up to the possible users to insist on appropriate remote sensors in satellites in the polar regions or opportunities will be lost to acquire useful information.

The pros and cons of remote sensing by satellites also should be considered carefully. Satellites probably should be used sparingly for things we really do not have to get that way. They should be used only when the cost is commensurate with the results. In the polar regions many of the unknowns are in the ocean, and there we should consider planting sensors on the ocean floor and looking up, instead of thinking only of looking down from satellites or aircraft.

Panel 7--Summary and A Look Ahead

PANEL MEMBERS

Henri Bader, Chr.
George Gryc
Frank A. Pitelka
L. O. Quam
Morton J. Rubin
Norbert Untersteiner
Kenneth Watson
Norman J. Wilimovsky

Clearly there is a need to take a hard look at remote sensing as a geophysical science. Thus far its success has been attained in remote-sensing investigations when they dealt with descriptive problems and qualitative results. The much tougher problems, such as investigations of heat balance and ice thickness, require quantitative rather than qualitative results. Here there is much more to be done. It was said earlier that the development of instrumentation has outstripped the experimentation to which the instruments are applied. For example, there is need for instrumentation that will provide a much better calibration of the atmosphere. The laser, for example, is a very good probe for calibrating the atmosphere. But we need lasers suitable for frequency changes by microns rather than by angstroms, and they are not yet available.

Furthermore, infrared scanners have been unreferenced for years. We need scanners that look at reference points, and we now have them. Radiometers do this, but radiometers do not give the

images that are given by infrared. More basic studies are needed also in the development of passive-microwave scanning if we are to do such scanning well.

There are in general four kinds of electromagnetic sensors: 1. radiometers, 2. spectrometers, 3. picture makers, and 4. multiband, multispectral systems. Within broad limits all four systems have the same information-band pass, but each kind uses the band pass in different ways to optimize certain things. Radiometers optimize for precision power measurements but are not very good for getting frequency distribution, nor for high resolution over large areas. They are very good in amenability to electronic processing. The spectrometer is an excellent instrument for obtaining wave-length distribution and for electronic processing. It is not very good for power measurements or for high geometric resolution over large areas. Cameras are excellent for high resolution over areas but are not as good in other respects. Multiband, multispectral systems are excellent for electronic processing. The important point to remember is that the different instruments are not competitive. They do different things. The choice of the method or combination of methods depends on the particular type of problem that is to be investigated.

Terrestrial biologists and ecologists have an advantage over oceanographers because their environment is relatively three dimensional, and furthermore, it is reasonably well known. Remote sensing in the field of

terrestrial biology is not likely to add much to the knowledge of environment, but it should add enormously to the fund of information on production potential and distribution. It is necessary, of course, to pick sites for systematic surveys to find out what remote sensing can do in this respect.

There is an enormous difference when the air-water interface is crossed. In water, where sound is the most effective remote-sensing method, discrimination is inversely proportional to range. Therefore, it does not appear that remote sensing is likely to be very useful in oceanography. The oceanographers really need a new approach. Holography and coherent sound may still hold some possibilities here. The only other recognized approach in oceanography is chemical. The real hope seems to lie in a system of underwater probes or "satellites" used on a continuous basis. A nuclear submarine would be ideal for this purpose, but the possibility of obtaining such a submarine for such a purpose is unlikely. So we must develop some unmanned vehicles. The aquatic biologists have a special sort of problem.

Remote sensing has a tremendous application to geologic mapping and mineral-resources investigations. The earth scientist should improve his capability for using remote-sensing data.

The atmospneric scientists have had an early start in the use of remote sensing. The great accumulation of data that results from

remote sensing does not especially bother atmospheric scientists. They are used to handling large volumes of data. The atmospheric scientists have learned to be selective in the use of data and have been practicing this sort of thing for many years. The atmospheric scientists have learned to use the data applicable to the particular purpose that they have in mind.

One of the most acute problems in the geophysical sciences is that of understanding the heat budget of the Arctic Ocean. That problem needs to be solved within the next two years. Apparently we now have most of the techniques and tools to do the job. Undoubtedly some instruments need to be improved, and there is need for more adequate funding. What appears to be lacking in geophysics is a coherent plan and a concerted effort. The problem is administrative and operational.

In general, it appears that most disciplines are potentially in good shape with respect to remote sensing except oceanography. New remote-sensing tools are needed for use under water. More attention must be given to instrument development, and more money will be required.

One of the outstanding problems in regard to remote sensing is the availability of data and the distribution of general information as to where the data can be found. A good deal of the information now is in rather obscure places, and a good deal of it is classified also. Examples of results from many kinds of remote sensing are available at such places

as the University of Michigan, the Geological Survey, NASA, the Army Topographic Laboratories, and the Army Terrestrial Sciences Center (formerly CRREL). Anyone wishing to explore sources of data can find an almost unlimited supply if he learns where to look for the information. A good place to start is to review the reports on the four remote-sensing symposia that have been held at the University of Michigan. Generally the cost of the information is nominal. NASA has a data bank at Houston. Furthermore, one can request missions by NASA aircraft, and the instruments available for use are described in a number of documents.

The use of the tower-mounted infrared viewer has thus far been somewhat neglected. More use of such a viewer would be a good way of gaining experience before mounting an instrument in an aircraft and a good way of comparing infrared output with ground truth.

A long discussion of the problems raised by the accumulation of large quantities of data and the possibility that many of those data are unlikely to be used led to the conclusion that the accumulation of data and their proper systematization and use are among the major problems that scientists face today in remote sensing.

Another problem is that of the next generation and the education of that generation in remote sensing. Several universities, possibly a dozen or more, have begun to graduate specialists in remote sensing.

Therefore, the next generation should be better informed and better prepared to grapple with remote-sensing problems.

Appendix 1

PROGRAM

Wednesday, March 6, 1968

Address of Welcome . . . . H. W. Love

Keynote Talk . . . . John C. Reed

Remote Sensing--Today and Tomorrow . . . . W. A. Fischer

Thursday, March 7
Morning

Panel 1--Ionosphere, Upper Atmosphere, and Atmosphere

Panel 2--Physical Oceanography

Afternoon

Panel 3--Biological Oceanography

Panel 4--Earth Resources, Geomorphology, Glaciology, and Permafrost

Friday, March 8
Morning

Panel 5--Terrestrial Biology

Panel 6--Applications to Development

Afternoon

Panel 7--Summary and A Look Ahead

Appendix 2

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